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PROBLEMS ASSOCIATED WITH THE STORAGE OF THERMAL COAL AND THEIR POTENTIAL SOLUTIONS

Dr. R.N. Chakravorty and H. Sahay

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by

Dr. R. Chakravorty*
Energy, Mines & Resources, Canada

and

H. Sahay, P. Eng**
Occupational Health and Safety Division

ABSTRACT

Recent incidences of fires and explosions in coal storage facilities in Alberta, Canada have resulted in renewed interest in the resolution of the problems relating to storage of coal. Field oriented research and investigation is being undertaken by the Calgary Coal Research Laboratory of Canada Centre for Mineral and Energy Technology, Engineering and Mines Branch (Government of Alberta) and some of the operating coal mining companies.

This paper discusses the progress made in Canda in combating this problem and the on-going and planned research activities. Whilst research to develop substantive criteria continues, in the interim, it is imperative that early warning systems to detect the incipient heating be developed.

Relatively new techniques of using inert gas to control heating in coal storage silos is also discussed.

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*Dr. R. Chakravorty, Head, Environmental Control, CANMET, Surface Mining Laboratory, Energy, Mines and Resources, Canada, P.O. Bag 1280, Devon, Alberta, TOC 1EO

**H. Sahay, P. Eng., Director Engineering and Mines Branch, Occupational Health and Safety Division, Community and Occupational Health, Government of Alberta, 10709 Jasper Avenue, Edmonton, Alberta, T5J 3N3

PROBLÈMES RELIÉS AU STOCKAGE DU CHARBON THERMIQUE ET SOLUTIONS POSSIBLES

par

M. R. Chakravorty*
Énergie, Mines et Ressources, Canada

et

H. Sahay, ingénieur**
Division de la santé et de la sécurité

RÉSUMÉ

Les incendies et les explosions qui se sont produits récemment dans les installations de stockage de charbon en Alberta, Canada, ont eu pour effet de renouveller l'intérêt en vue de trouver une solution au problème de stockage du charbon. Des activités de recherche et des études sur le terrain ont été entreprises par le Laboratoire de recherche sur le charbon à Calgary, Centre canadien de la technologie des minéraux et de l'énergie, Division du génie et des mines, (Gouvernement de l'Alberta) et certaines sociétés houillères.

Le rapport porte sur les progrès réalisés au Canada en vue de résoudre ce problème et sur les recherches en cours ou sur celles que l'on projette de réaliser. Bien que les études en vue d'établir des critères valables se poursuivent, il est essentiel que des systèmes d'avertissement précoce soient mis au point afin de détecter les sources de chaleur dès le début.

Les nouvelles techniques comprenant l'utilisation du gaz inerte pour contrôler la chaleur dans les silos servant à stocker le charbon sont également présentées.

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*M. R. Chakravorty, Chef, Contrôle environnemental, CANMET, Laboratoire d'exploitation minière à ciel ouvert, Énergie, Mines et Ressources, Canada, B.P. Sac à dépêche 1280, Devon (Alberta) TOC 1EO

**H. Sahay, ingénieur, Directeur de la Division du génie et des mines, Division de l'hygiène professionnelle et de la sécurité au travail, Gouvernement de l'Alberta, 10709 Jasper Avenue, Edmonton, (Alberta), T5J 3N3

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Dr. R. Chakravorty
Head, Environmental Control
CANMET, Surface Mining Laboratory
Energy, Mines and Resources, Canada
and
E. Sahay, P.Eng.
Director Engineering and Mines Branch
Occupational Health and Safety Division
Community and Occupational Health
Government of Alberta

INTRODUCTION

Recent incidences of fires and explosions in coal storage and loading facilities in Canada have resulted in a renewed interest in the study and resolution of problems relating to such hazards. Investigation into these incidents has shown that spontaneous combustion and accumulation of methane gas are the two major causes responsible for such ocurrences.

There is no single criteria by which one can assess whether storage of thermal coal will lead to a fire caused by spontaneous combustion. In general, thermal coals are more susceptible to spontaneous combustion compared to high rank metallurgical coals. Methane emission, on the other hand, is greater in the higher rank coals.

Another factor which is of concern is the temperature at which coal is stored in a silo. Research has shown that the oxidation proceeds at an accelerated rate when the temperature of coal reaches 70°C or more. Reabsorption of moisture by partially dried coal also results in a significant increase in temperature thereby enchancing the potential for fire. It has also been observed that the rate of methane desorption from coal increases with the increase in temperature. To reduce oxidation and methane emission it is, therefore, essential to maintain coal temperatures as low as possible.

In recent years field oriented research and investigation has been undertaken by CANMET, the Occupational Health and Safety Division of Alberta and some of the operating companies to mitigate problems associated with the storage and transportation of coal.

HEATING IN COAL STOCK PILES

The risk of spontaneous heating in coal stockpiles, particularly with low rank coal, is rather high. In general, the sign of heating in thermal coal stacks are noticed within a period of 10-12 weeks. There are instances where heating has taken place within 4-6 weeks after stacking under favorable heat accumulation conditions.

The mechanism which occurs during development of heating in a coal stockpile is no different than that observed during mining. An environment for heat accumulation is essential for spontaneous heating to occur. No fire will occur if the coal is spread out and the height of the stack is kept low.

Although initial oxidation of freshly exposed coal surface is very rapid, it generally declines with time. If no heating has taken place within the first few months, the risk is considerably reduced provided the stack remains undistrubed.

The nature of self heating phenomena in coal stacks were studied by Chakravorty et al [1]. No heating was noticed in stacks which were thoroughly consolidated. One of the unconsolidated stacks made from freshly mined sub-bituminous coal actually caught fire within a period of nine weeks. The temperature of the coal stack slowly increased to 90°C over a period of 7 weeks, then maintained a temperature of 90°-99°C for nearly 7 days. Smoke appeared on the 60th day. Within 24 hours, there was an active fire from the toe to a height of 0.8m along the slope. During the initial stage, fire penetrated only to a depth of 15 cm from the surface. There was a shower the day before the smoke appeared. This further confirms that addition of moisture in a partially heated stack accelerates the process of self heating. The location of hot spots in a coal stack also depends on the local heat accumulation conditions as indicated in Figure 1.

Studies on self heating, using Australian coal, were discussed in a recent review [2]. Hot spots began to develop in a partly compacted stacks after 2-4 weeks. The temperature of the coal stack, which was well compacted on both the top and sides, stabilized within a period of 6 months at 30°-40°C. No heating was noticed

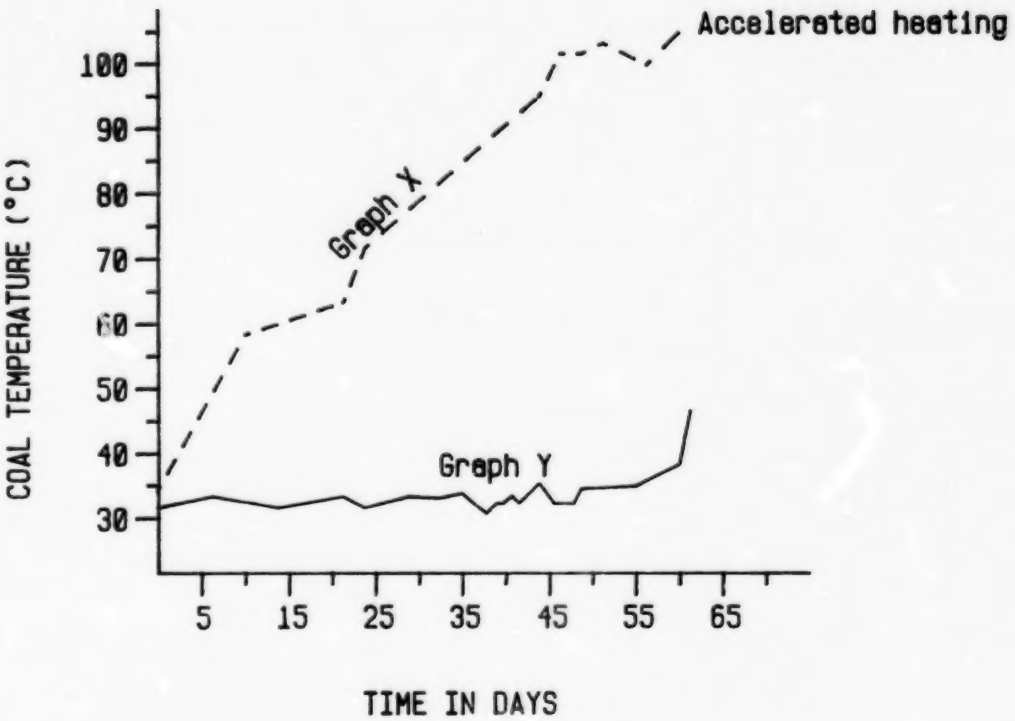

FIG.1-VARIATIONS IN TEMPERATURE WITH TIME IN A COAL STACK (LOW RANK THERMAL COAL). GRAPH X AND GRAPH Y SHOW TWO DIFFERENT LOCATIONS IN THE SAME STACK.

over a period of two years. However, this stockpile was sprayed with surfactants as an additional precautionary measure. Figure 2 shows the temperature variations in treated, untreated and compacted stockpiles.

It is difficult to get an agreement on the critical stockpile temperature for accelerated development of heating. The recommended temperature is between 50°-90°C, depending on the spontaneous combustion liability of the coal and the method of stacking. With most coal, once the temperature exceeds 70°C, there is a possibility that the temperature may rise dangerously within a short period. The aim should be to minimize any temperature rise. In a well compacted stack, the temperature rise should not be more than a few degrees.

SAFE STORAGE PRACTICES

The method of coal storage will depend on factors such as rank of coal, facilities avialable and the length of time for which the coal will be stored. It is essential, as a first step, that there should be either adequate ventilation or total elimination of air flow through the stack as completely as possible. Storage with ventilation is only recommended for large and graded coal. However, there is no control over slacking which may restrict air flow and eventually cause heating.

The most statisfactory method of coal storage is in well compacted heaps with layers about 0.6m in thickness. Each layer should be rolled before commencing the next. Care should be taken to avoid segregation, particularly lumps rolling down the sides of the pile. The sides should be thoroughly consolidated and hollows at the top should be avoided.

Coals from different ranks should not be stored together. Heating can be caused by putting fresh coal on top of old coal. If the stacking of coal of different sizes becomes unavoidable, the risk of heating could be reduced by alternating layers of fine coal and large coal.

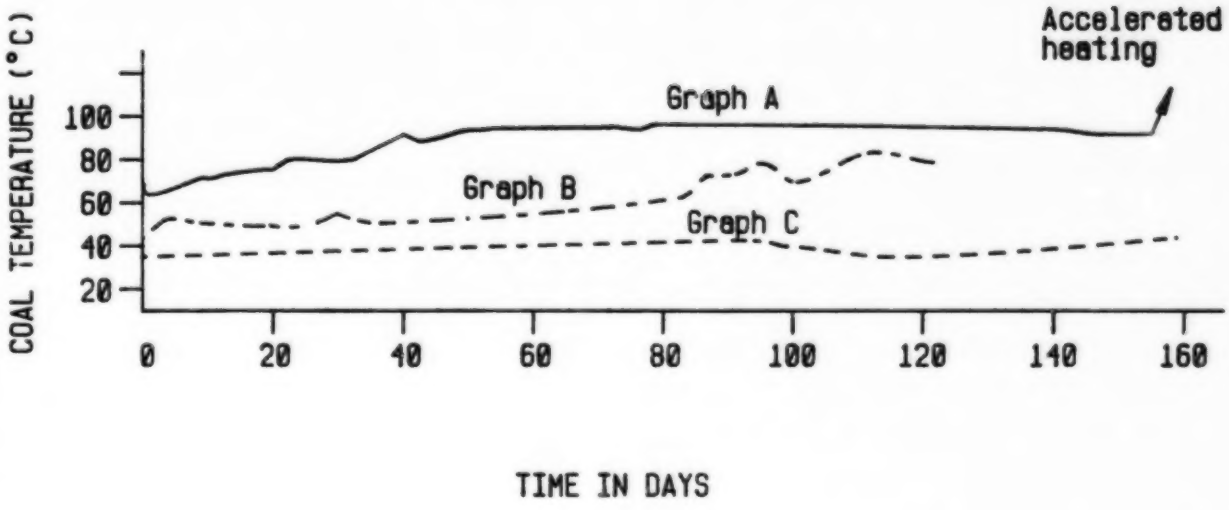

FIG.2 - TEMPERATURE VARIATION IN THREE DIFFERENT COAL STACKS. A - UNTREATED COAL, B - COMPACTED PILE, C - SURFACTANT TREATED COAL (ORIMOTO).

Spraying of road tar provides an effective seal to air leakage and is recommended for coal stacks which are likely to be left over for a long period. Road tar also helps in preventing channels caused by rain. Surfactants of organic binders normally used for dust control were found to be quite effective in reducing spontaneous combustion in coal stacks.

Storing coal in vertical bunkers or coal silos are a common practice at mine sites. Such bunkers or silos reduce air leakage to a certain extent. The risk of spontaneous heating could be further reduced by blanketing the coal with nitrogen. Artificial aging and treating the coal with carbon dioxide can reduce the risk of spontaneous combustion. Spontaneous heating in coal stockpiles can be prevented by immersing the coal for a short time in oil at 300°- 400°C before stacking. Commercial viability of this semi-cabonization process needs careful evaluation.

EARLY DETECTION OF HEATING

Early recognition of heating in a storage facility is absolutely essential for the prevention and control of fire. Any fire which can be detected at an early stage can save the facility from considerable damage and financial loss. Extensive research and investigation in different countries have indicated that the study of combustion gas is the best approach to detect heating at an early stage.

Methods Based on Products of Combustion

The main products of combustion during low temperature oxidation of coal are carbon dioxide, carbon monoxide and water vapour. It has also been observed that production of these gases increases with the increase in temperature. Carbon monoxide has proven to be a more specific product of combustion particularly during low temperature oxidation of coal. Graham's method for early detection of heating is based on carbon monoxide/oxygen deficiency ratio calculated from the analysis of return air samples. Over the years, many heatings have been detected successfully using this ratio. The greatest advantaage with the carbon monoxide/ oxygen deficiency ratio is the fact that it is independant of any dilution by fresh air. The CO/O_2 deficiency ratio will increase with the rise in temperature but the nature of increase will also depend on the rank of coal.

Research carried out in Japan established that production of carbon monoxide alone cannot be regarded as a definite sign of heating unless it is accompanied by the production of ethylene. Further research has also shown that ethylene and alkene ratio (CH_4/C_4H_{10}) are a better guide compared to the trend shown by carbon monoxide alone [3]. U.K. studies on the nature of oxidation products indicated that although a large number of saturated and unsaturated hydrocarbons, such as methane, ethane, ethylene, and acetylene are produced during the early stages of oxidation, none of the gases provides a better alternative to carbon monoxide for early detection of spontaneous combustion [4]. CANMET studies on Canadian coal also produced similar results as shown in Figure 3 [5]. It is obvious from the graph that carbon dioxide is produced in detectable amounts even at a temperature of 70°C. Hydrogen and ethane could be detected at an approximate temperature of 100°C and ethylene and acetylene was observed in the product gases over a temperature of 150°C. Studies in West German laboratories showed that a temperature of 100°-120°C is required before benezene is produced in detectable amounts.

Thermal Methods

It is generally believed that heat produced during the early stage of oxidation preceeds any product of combustion. As such, the temperature of the coal mass is expected to show some increase due to heating much before the actual fire occurs in a coal storage silo or in stockpiles. In large stockpiles, using thermistors or thermocouples for monitoring heating has proved somewhat inconvenient because of the large number of temperature probes needed to identify a hot spot.

In recent years infra-red scanners and thermometers proved useful in locating hot spots in coal stacks and in underground coal mines. The infra-red instruments are portable, easy to use and capable of remote measurement thus eliminate large scale instrumentation required using thermistor and thermocouples. Infra-red thermometers can be used for measuring the temperature of the hot surface accurately. Most instruments are provided with a telescopic sight which helps in pinpointing the hot spot while carrying out thermal surveys. Figure 4 shows routine thermal surveys carried out using infra-red scanners and thermometers.

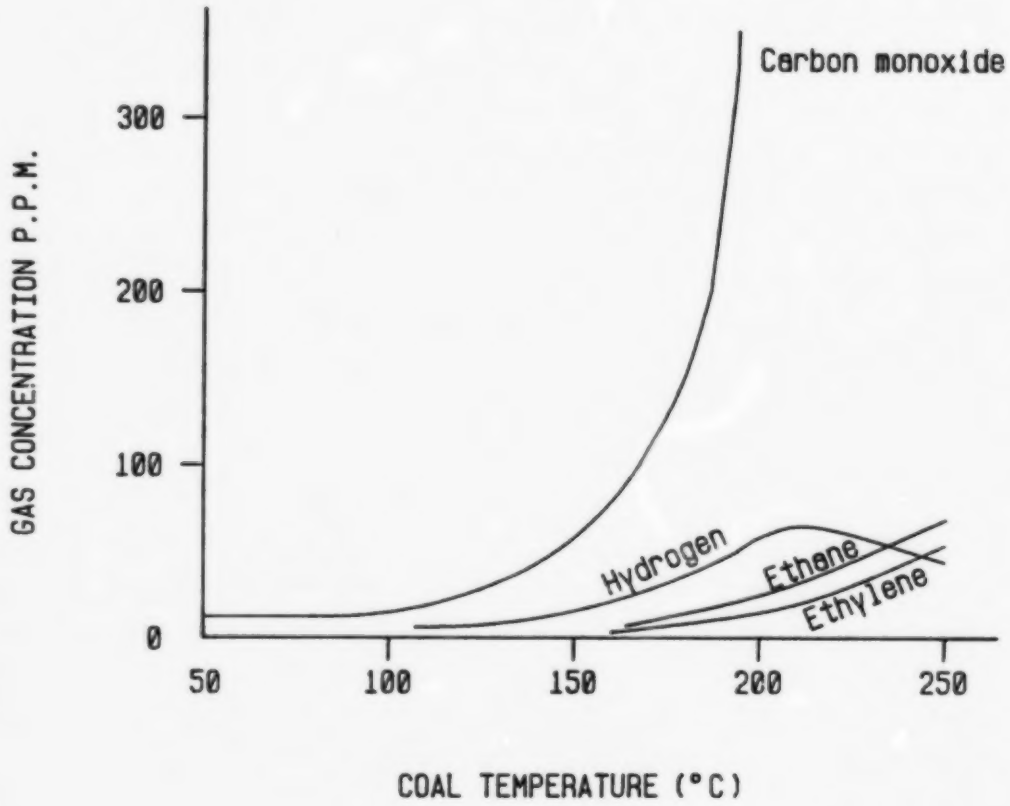

FIG.3-GRAPHS SHOWING VARIATIONS IN GAS CONCENTRATIONS WITH CHANGES IN TEMPERATURE

INFRARED SCANNER BEING USED FOR THERMAL SURVEY NEAR UNDERGROUND STOPPINGS

INFRARED THERMOMETER BEING USED FOR LOCATION OF HOT SPOT NEAR A CAVED AREA

INFRARED THERMOMETER IS BEING USED FOR STUDYING THE SPREAD OF FIRE IN OUTCROPED AREAS

FIG. 4 - ROUTINE THERMAL SURVEYS BEING CARRIED OUT USING INFRARED SCANNERS AND THERMOMETERS

Infra-red imagers developed in recent years can present a detailed thermal picture of the entire scenes within the field of view of the instruments. It is thus capable of locating hot spots in a large stockpile with remarkable speed and accuracy. The spread of heating can also be assessed with considerable ease. It is also possible to take thermal pictures of the area scanned using a polaroid camera attachment.

In recent years considerable progress has been made in infra-red technology by introducing video convenience and computer based interpretation of the thermal picture. The computer can draw trends, calculate rate of temperature increase and include many other options in the presentation of data. Results obtained during field surveys can be analysed in the laboratory and where necessary, a micro-computer is interfaced with mini-computers for complex image analysis. However, the success of this technique depends on correct interpretation of thermal images.

A number of heatings were successfully detected by CANMET researchers using this infra-red technique. In almost all cases routine visual inspections did not indicate anything abnormal. For the location of hot spots in coal stacks and in coal outcrop areas, infra-red scanners proved particularly useful. Figure 5 shows some of the actual photographs of hot spots located during thermal surveys in Canadian coal operations and in coal stockpiles.

Continuous Monitoring Systems

The continuous monitoring of air within the storage facility is likely to present a more complete picture of conditions at all times and will prove beneficial in ascertaining the actual conditions within the coal storage system during weekends or when the storage facility is left idle for various reasons.

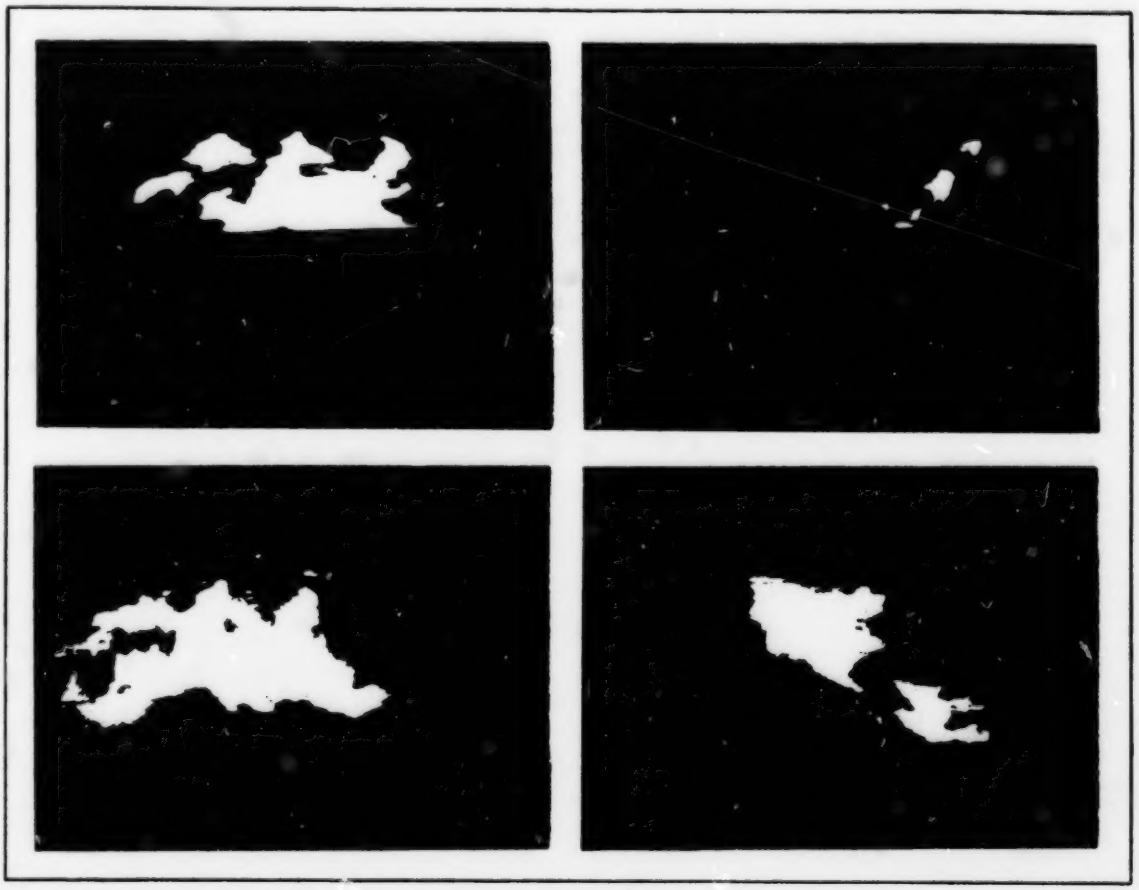

FIG. 5 - PHOTOGRAPH OF HOT SPOTS LOCATED DURING THERMAL SURVEY IN COAL OUTCROP AREA AND IN COAL STOCKPILES

Two types of monitoring systems can be used for early detection of heating, namely the tube bundle and telemetric system. The tube bundle system operates by drawing air from strategic locations into individual tubes. The tubes are connected to an analyser for analysis of carbon monoxide, carbon dioxide, methane and oxygen. The telemetric system uses sensors to analyse the mine air at strategic locations. The information from the sensors can be transmitted to the computer for data processing. The transmission of data using this system is almost instantaneous. One of the major advantages of automated monitoring systems arises because of the capability of the computer to process large quantities of data, indicate when preset alarm limits have been exceeded and provide daily reports, trend analysis, etc. The continuous monitoring systems used in Canadian mining operations proved useful for early detection of heating and ensured safer working environment.

INERTIZATION

The principle of fire inertization is to reduce the concentration of oxygen in the atmosphere. To prevent explosion of a methane air mixture, it is necessary to reduce oxygen content to below 12% by volume. However, oxygen content should be reduced to below 3% to prevent fire caused by spontaneous heating. Major advances have been made in recent years towards control of mine fires through the use of inert gas. Inertization makes it safe for rescue people to enter the affected area to fight fire without fear of explosion. The safer environment created by inertization is conducive to better and more effective work by rescue teams during fire fighting. In most applications to date, nitrogen has been used for inerting, however, carbon dioxide and generators which produce oxygen free exhaust gas have also been found effective. By continuously injecting nitrogen at a slow rate, the heating in the coal silo can be prevented. Coal silos should be equipped with facilities that can make use of nitrogen in inertization with minimum delay in the event of a fire. These facilities should include necessary fittings for a nitrogen tank and a portable evaporator. Carbon dioxide may be used instead of nitrogen and is occassionally chosen in preference to nitrogen particularly where the heating is at the bottom of the stockpile. A number of heating in coal mine operations were successfully controlled using inertization techniques in Canada.

METHANE CONTROL

Explosion of methane in coal storage silos and coal ships is an ever present hazard. Effective control of methane during mining, storage and transportation is considered essential for the safe handling of coal. As mentioned earlier, hazardous concentrations of methane in coal silos have caused several serious explosions in Canada in the recent past. Recent investigation by CANMET and Occupational Health and Safety, Alberta have shown, beyond a doubt, that considerable accumulations of methane do occur in coal storage silos[6]. Recent explosions on ships carrying coal strongly indicate that similar conditions also exist in ship holds. Investigations have also shown that the main concentration of methane occur within the coal pile itself[7]. Consequently, ventilation will not be an effective method for removing the methane. The thrust should be on exclusion of potential sources of ignition and to place coal in an inert atmosphere. Investigations are continuing to search for better methods to implement both of these principles. CANMET has initiated work on biological control of methane as a rather unconventional technique for methane control in coal storage silos.

A review of literature indicated that microbiological control of methane is feasible. Methane oxidizing bacteria was isolated from a number of coal samples collected from Canadian mining operations. Labratory studies have shown that these organisms can remain active over an extended period and the rate of methane oxidation to carbon dioxide is quite appreciable. Small laboratory scale experiments were successfully scaled up to allow 10 kg of coal to be tested in a model silo and rates of methane oxidation was found to be equally active. Work is underway to carry out tests on a larger silo using 2-3 tons of coal. So far results are encouraging and it appears this technique may be used successfully to control methane explosions provided this technology proves suitable and cost effective in full scale commercial operations.

DESIGN CONSIDERATIONS AND RECOMMENDATIONS:

1. The ventilation system of the storage faciltiy should be designed bearing in mind the possible accumulation of methane gas, dust and the onset of spontaneous combustion. Provision for adequate quantity of fresh air should be made using positive ventilation to dilute the contaminants within the acceptable level and prevent accumulation of flammable gases.

2. To reduce the possibility of ignition, equipment and electrical installations must meet the appropriate hazardous classification code for flammable gases.

3. Installation of the gas monitoring system in the storage facility should form an integral part of the provision. Methanometers should be installed at strategic locations in the storage facilities and be interlocked with the electrical system so that power can be shut off when readings exceed the statutory limit. Possible use of infra-red scanners to detect unacceptable hot coal on the conveyor belts before loading should be investigated.

4. Dead zones should be avoided in silos to prevent the accumulation of coal and possible heating due to spontaneous combustion. Similarily, attempts should be made to reduce degradation of coal during dumping.

5. Operating procedures should be developed to handle emergency situations with proper training and exercises.

6. Use of explosion barriers, especially in the underground portion of the reclaim tunnel, should be given serious consideration. Similarily, cladding in enclosed galleries should be such that they could be easily dislodged and help dissipate the explosive energy.

7. Continuous monitoring of methane and carbon monoxide within a coal storage facility is absolutely essential to prevent fire and explosion. Thermal surveys of all areas considered vulnerable to spontaneous combustion should be carried out regularly. The discharge area in a coal silo is usually a

7. (cont'd)
potential source of heating caused due to leakage of air. Installation of thermocouples near the discharge area may help in monitoring the temperature rise. A combination of infra-red thermometry and continuous monitoring of carbon monoxide should be able to provide adequate warning to control the onset of heating in the storage facility before it is too late.

8. The practice of storing coal at high temperatures should be discouraged. To prevent an outbreak of fire, corrective measures should be undertaken once the temperature of the coal stored exceeds 50°C.

9. Use of inert gas has proved useful both for the control of fires and for inertization of flammable atmosphere. All coal storage facilities should consider having provisions for inertization so that heatings can be dealt with without delay.

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